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STUDY OF POWER MANAGEMENT TECHNOLOGY FOR ORBITAL MULTI-100KWe APPLICATIONS

VOLUME 3 • REQUIREMENTS

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16. Abstract

This study examines mid-to-late 1980's power management technology needs to support development of a general purpose space platform, capable of supplying 100 to 250 KWe to a variety of users in LEO.

To that end, a typical, Shuttle assembled and supplied space platform is illustrated, along with a group of payloads which might reasonably be expected to use such a facility. Examination of platform and user power needs yields a set of power system requirements used to evaluate power management options for life cycle cost effectiveness.

The most cost-effective AC/DC and DC systems are evaluated, specifically to develop system details which lead to technology goals, including: array; and transmission voltage, best frequency for AC power transmission, and advantages and disadvantages of AC and DC system for this application.

Finally, system and component requirements are compared with the state of the art to identify areas where technological development is required.

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1

SCOPE

This document defines the system requirements for a multihundred kilowatt power management system (PMS) which would be utilized aboard a large, manned multi-purpose space platform during the mid-to-late 1980s time frame.

1.1 OBJECTIVE

The objective of this document is to establish a set of system requirements that will be the basis for (1) establishing a group of candidate PMS design concepts and (2) conducting trade studies to evaluate and select the most cost-effective approach.

1.2 ASSUMPTIONS AND GROUNDRULES

a. The space platform will operate in low earth orbit (LEO).

b. The PMS design shall be based upon mid-to-late 1980s technology readiness.

c. Minimum system useful life shall be ten years.

d. All PMS components and assemblies launched into earth orbit shall be compatible with Shuttle. No other large launch vehicle will be assumed available in this time frame.

e. The PMS shall be designed for on-orbit maintenance and repair capability.

f. The power source will be a planar, silicon photovoltaic array.

g. Array and storage sizing shall be based on continuous operation of load power in the range of 100 - 250 kWe average.

h. PMS design studies shall use the clean sheet approach - no combining of several smaller power systems.

i. The PMS design approach shall be consistent with extended visits by man.

1.3 ACRONYMS

AC	Alternating Current	LEO	Low Earth Orbit
BM	Berthing Module	LM	Logistic Module
CCM	Control Center Module	MDL	Multidiscipline Laboratory
C.G.	Center of Gravity	MPL	Material Processing Laboratory
CHM	Crew Habitat Module	OTV	Orbit Transfer Vehicle
CM	Construction Module	PEO	Polar Earth Orbit
DC	Direct Current	PM	Power Module
GEO	Geostationary Equatorial Orbit	PMS	Power Management System

2

APPLICABLE DOCUMENTS

The following documents provide guidance in defining design and operations requirements for the PMS. The list contains specifications, standards, and other requirements that are representative of those that will be imposed in later development phases. Consequently, and to the extent possible, they should be considered during preliminary design and system definition.

2.1 SPECIFICATIONS

MIL-E-6051, "Electromagnetic Compatibility Requirements, Systems"

2.2 STANDARDS

a. MIL-STD-1541, "Electromagnetic Interference Characteristics Requirements for Equipment"

b. MIL-STD-462, "Electromagnetic Interference Characteristics, Measurement Of".

c. MIL-STD-1472B, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities".

d. MSFC-STD-512A, "Man/System Requirements for Weightless Environments", 1 December 1976.

2.3 OTHER PUBLICATIONS

a. NASA JSC 11123, "STS Payload Safety Guidelines Handbook".

b. ICD 2-19001, "Shuttle Orbiter/Cargo Standard Interfaces".

c. NASA TMX-53865, "Natural Environment Criteria for 1975 - 1985 NASA Space Stations".

d. NASA SP-208, "The Prevention of Electrical Breakdown in Spacecraft"

e. NASA JSC-10615, "Shuttle EVA Description and Design Criteria", May 1976

f. NASA JSC 07700, Vol XIV, "Space Shuttle System Payload Accommodations".

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REQUIREMENTS

3.1 SYSTEM DEFINITION

The Power Management System (PMS) includes all functions associated with transmission, distribution, processing, and conditioning of electrical power between the source, the energy storage device, and the loads. The power source, storage device and loads are not part of the PMS, but their characteristics will influence the design of the PMS.

3.1.1 GENERAL DESCRIPTION. The major elements of the space platform electrical power system are identified in Figure 3-1. The PMS is shown interfacing with power sources, energy storage, command and control, and the loads. However, portions of the power management system may be physically located with other system elements. For example, some aspects of the power conditioning function may be located on the solar array, and voltage regulators may be located at the loads. Choices between these alternatives will be made by trade studies.

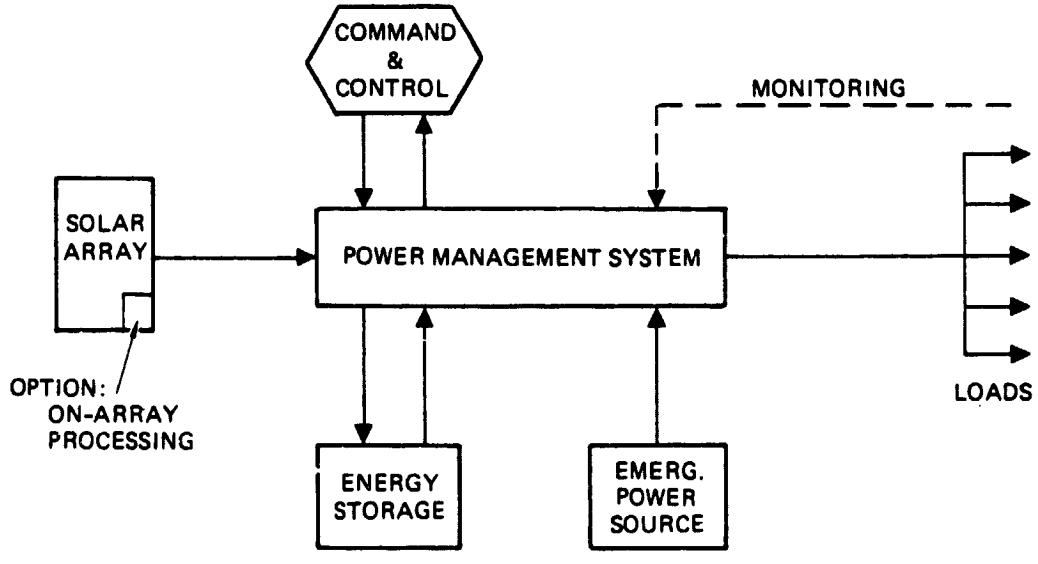

Figure 3-1. Electrical power system major elements.

The Power Management System (PMS) performs the functions of power transmission, voltage and frequency regulation, DC to AC and AC to DC conversion, battery charge regulation, switching, circuit protection, and distribution to loads. The major hardware components of the PMS are listed in Table 3-1.

Table 3-1. Major PMS components.

Power Transformers
Switchgear
Inverters (DC - AC)
Converters (DC - DC)
Regulators
Source Conditioners
Load Conditioners
Battery Power Conditioners
Conductors/Connectors
Rotary (joint) power transfer
Monitor/Control equipment

The solar array will be sized such that the electrical system average electrical power output will be 100 to 250 kW. Array voltage output may be in the range of 28 to at least 1000 volts. Transmission lines may be high or low voltage, AC or DC. Energy storage may be any of the following devices:

a. Advanced Ni Cd battery
b. Ni H_2 battery
c. Regenerative fuel cell.

Command and control of the PMS will be provided thru the space platform data management system; both on-board and ground-controlled modes will be possible.

An emergency power source is required. The source may be primary or secondary batteries, or fuel cells.

The electrical loads serviced by the PMS consist of space platform subsystems such as environmental control and life support, communications, data management, galley systems, waste management, attitude control and illumination, and mission peculiar equipment such as experiment apparatus and construction equipment. The electrical loads associated with the baseline space platform are defined in Subsection 3.2.

3.1.2 BASELINE SPACE PLATFORM. A baseline space platform configuration is defined in this section based upon the concepts developed in the Space Station Systems Analysis Studies conducted for NASA by McDonnell Douglas Corporation and Grumman Aerospace Corporation and as constrained by the groundrules and assumptions of this study. The baseline configuration is shown in Figure 3-2. The selected baseline is

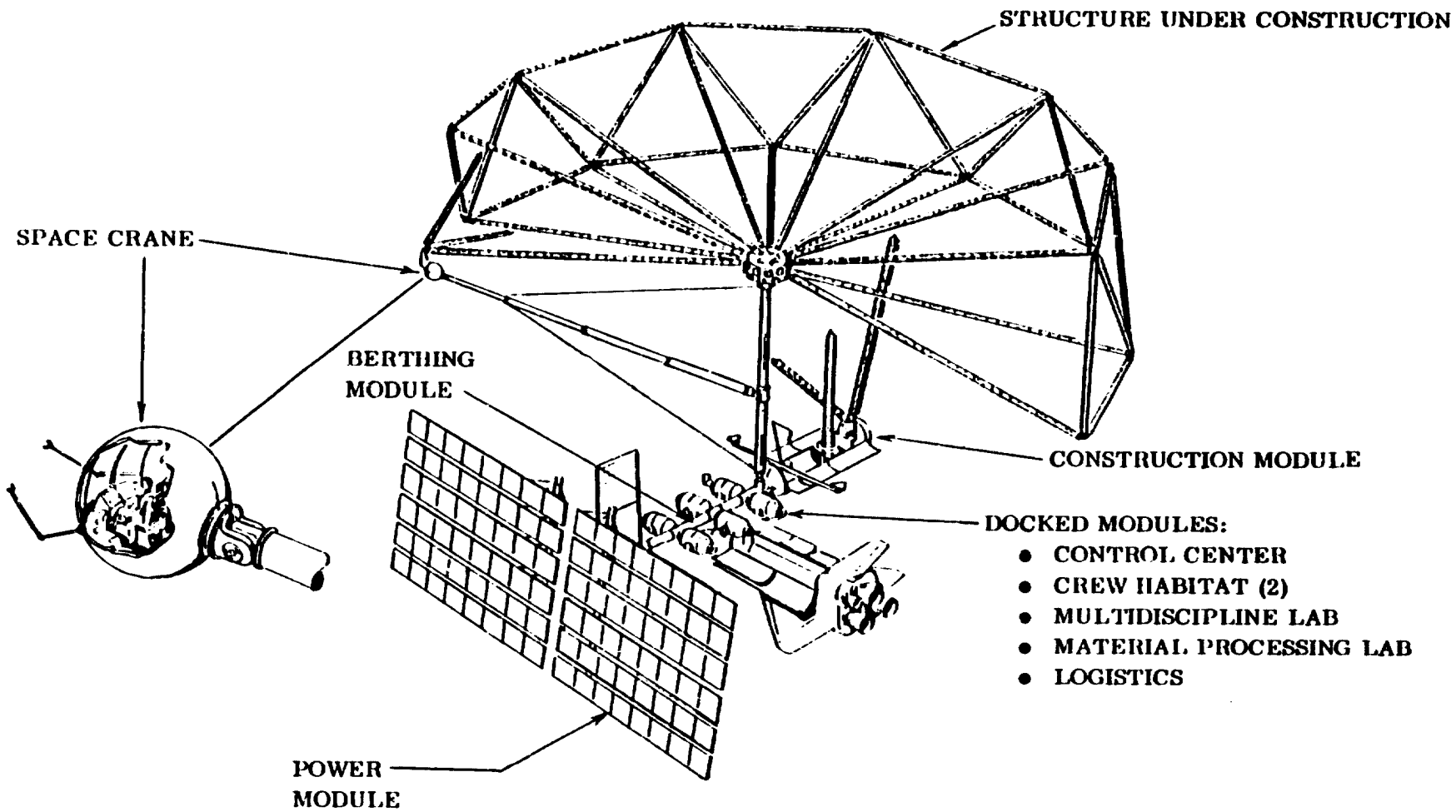

Figure 3-2. Baseline space platform configuration.

a configuration which could exist in the early 1990s era, and one which would evolve through a succession of build-up and operational phases of shuttle-compatible modular elements.

In the configuration shown, the space platform has the capability for continuous manned operation with a crew of 20, supported by periodic logistics flights of the space shuttle for resupply of materials and consumables, crew rotation, and delivery of space manufactured products and waste materials to earth. A regenerative life support system is employed to reduce the amount of life support system consumables carried on the logistics flights.

The major elements that comprise the baseline space platform cluster are the power module, berthing module, modules for operational control, crew habitats, laboratories, construction, and cargo storage, as well as a space crane. The functional interfaces between the platform elements are identified in Figure 3-3. A brief description of each of the elements follows.

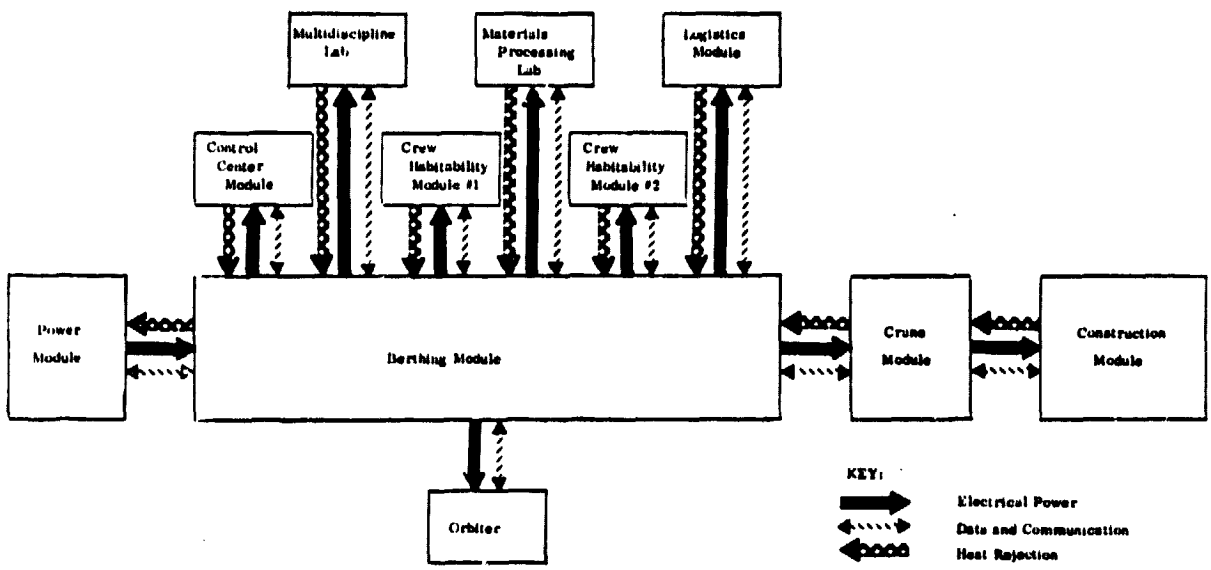

Figure 3-3. Space platform elements and interfaces.

a. Power Module - The power module (PM) provides the photovoltaic power source, power conditioning equipment, energy storage, and some elements for power distribution, heat rejection, attitude control, and stationkeeping. In the first phase of space platform operation, when orbital activities are relatively low and power demand is low, only a fraction of the solar array panels, storage batteries, and power management system components are installed. Over a period of years additional equipment is added in several steps, culminating in the baseline power module which can deliver 250 kWe continuous average power when solar illumination is available for a minimum of 62% of the orbit period.

During the portion of logistics flights when the shuttle Orbiter is docked to the space platform, the Orbiter's fuel cells are shut down and power is supplied to the Orbiter's electrical power buses by the space platform. The Orbiter crew lives aboard the Orbiter during this period, and utilizes the Orbiter habitability facilities. The Orbiter's life support, thermal control, communications, and data management subsystems are active, drawing power from the Orbiter's power distribution system in a normal operating mode.

The PMS transmission/distribution lines will necessarily be segmented because of the modular construction of the space platform. Figure 3-4 illustrates the distances over which the system must carry power to the various berthing/docking interfaces. In addition, the distribution system within each module must carry power up to 18.3 m along the length of the berthing module and 15.2 m along the lengths of the other modules.

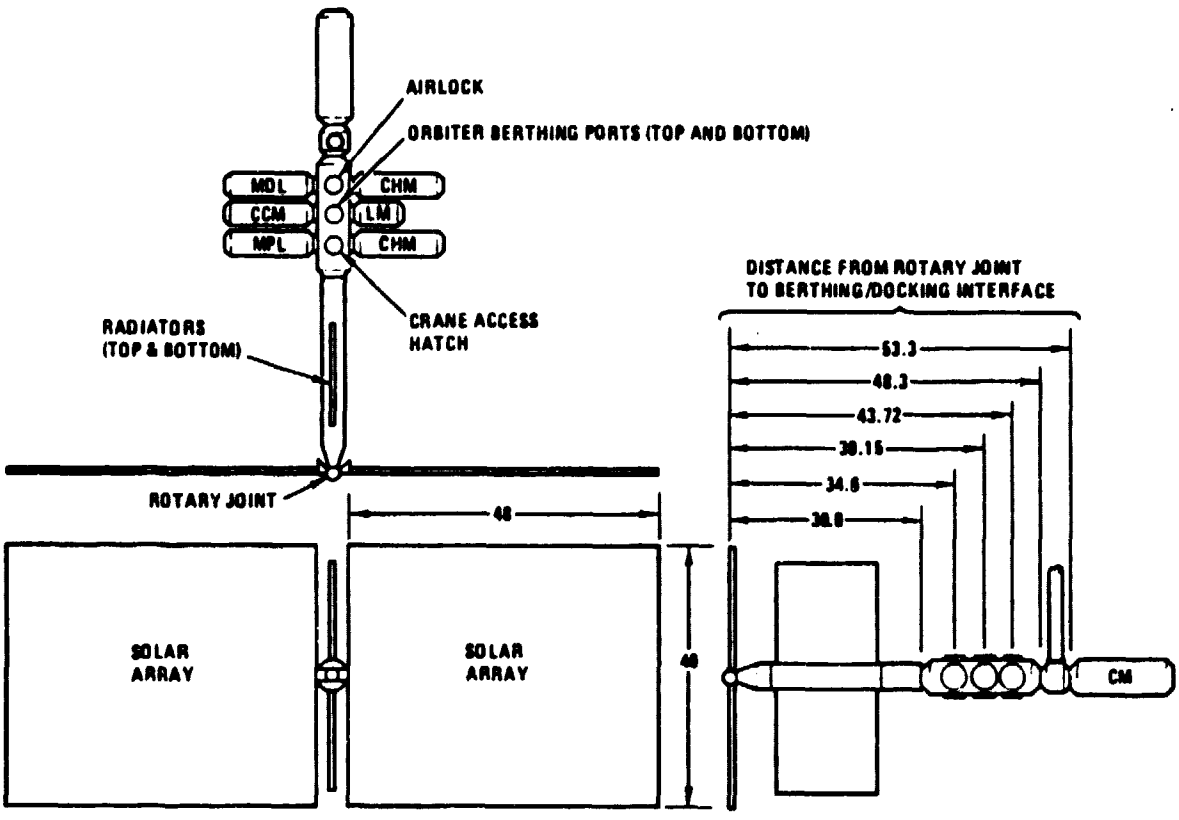

Figure 3-4. PMS spatial relationships (dimensions in meters).

3.1.3 MISSIONS. The missions for an evolutionary, multipurpose space platform vary with time and cover a spectrum of activities from science and applications experiments and observations to construction of large space structures and in-orbit support of orbit transfer vehicles (OTV).

The baseline space platform is configured to conduct experiments in physics, chemistry, materials processing, and life sciences, to make observations in earth sciences and astronomy, and to construct large structures that support RF receiving and transmitting equipment and solar power collection and conversion equipment.

The Space Station Systems Analysis studies have identified beneficial uses for low earth orbit (LEO) space platforms in a range of inclinations from 28.5 to 55 deg, and in a range of circular orbit altitudes from 370 to 650 km (200 - 350 n mi), as well as later applications in polar earth orbit (PEO) and geostationary equatorial orbit (GEO). The following orbit parameters have been established for the baseline space platform:

a. Inclination: 28.5 deg
b. Altitude: 400 km

In the early operational phases of the space platform, stationkeeping impulse will be provided at 60 day intervals by the Orbiter. However, as the size and mass of the platform and structures under construction increase to large-scale proportions, flight control subsystem elements will be added to enable the space platform to perform the stationkeeping function.

Experiment and construction activities are scheduled for around-the-clock operations. Three eight hour shifts will be worked, with overlap at each shift change, and a mid-shift break for eating and personal hygiene. The nominal assignment of crew duties is as follows:

a. Experiments and Construction: 14 men
b. Housekeeping, communication, data management: 6 men
c. Total: 20 men

The tour of duty for each crewman is 180 days. Approximately one third of the crew is rotated each 60 days during routine logistics flights.

Propellant resupply of orbit transfer vehicles has been estimated to require 1000 metric tons per year by the early 1990s. The space platform will serve as the orbital depot where large, heavily insulated, propellant storage tanks will be berthed. To eliminate boiloff losses, the storage facility will be equipped with refrigeration equipment that will reliquefy the hydrogen and oxygen gases and return them to the storage tanks. The daily processing load of the reliquefication plant is estimated to be 137 kg of H_2 and 351 kg of O_2 per day.

TABLE 3-3.

ACTIVITIES AND LOAD PROFILE MODULE:

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
Multidiscipline Lab	14.8	16.8	24.8	16.2	16.2	22.8	19.4	21.8	28.2	18.2	19.8	15.4	21.4	23.8	29.2	15.6	14.8	24.8	19.4	28.2	27.2	18.2	17.8	17.8
Material Processing Lab	47.5	47.5	47.5	47.5	47.5	47.5	47.5	50.4	57.3	54.3	57.3	18.5	22.3	19.3	17.3	71.1	70.3	60.3	60.3	49.5	70.3	70.3	60.3	50.3
Construction Module	15.8	15.8	15.8	14.2	15.8	15.8	15.8	15.8	15.8	15.8	15.8	14.2	15.8	15.8	15.8	15.8	15.8	15.8	15.8	14.2	15.8	15.8	15.8	15.8
Crane	5.5	5.5	5.5	2.8	5.5	5.5	5.5	5.5	5.5	5.5	5.5	2.8	5.5	5.5	5.5	5.5	5.5	5.5	5.5	2.8	5.5	5.5	5.5	5.5
Control Center Module	14.8	17.8	14.8	13.7	11.2	17.8	16.5	13.3	18.3	22.4	17.5	15.3	16.8	22.4	28.7	17.5	19.1	23.2	18.3	15.3	16.8	21.6	19.8	17.5
Crew Habitat Module #1	6.8	6.8	6.8	7.3	8.1	5.5	5.5	5.5	6.8	5.5	6.8	6.8	7.8	5.5	5.5	5.5	6.8	5.5	6.8	6.8	8.4	6.8	6.8	6.8
Crew Habitat Module #2	6.3	5.5	6.8	6.8	7.6	6.5	6.8	6.8	6.8	6.8	6.5	6.5	7.6	6.8	5.5	5.5	6.3	5.5	6.8	6.8	7.1	6.8	5.5	5.5
Berthing Module	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2
Logistics Module	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Power Module (ECLSS only)	8.2	8.4	11.1	8.1	8.3	8.7	8.3	8.6	9.6	9.8	9.8	8.6	7.5	7.8	7.8	9.5	9.5	9.8	9.2	8.4	10.2	9.8	9.2	8.5
Total Cluster Load Profile, kW	131.8	135.7	143.2	130.8	134.3	142.8	138.1	148.8	168.8	149.1	149.8	98.7	117.5	118.8	128.5	158.2	158.7	162.4	152.8	136.8	174.8	168.7	152.8	138.3
Total Daily Energy: 3,413.5 kWHr																								
Average Load: 142.23 kW																								
Low: 98.7 kW																								
High: 174. kW																								

TABLE 3-4.

ACTIVITIES AND LOAD PROFILE MODULE: MDL

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
LOADS - Support																								
ECLSS, illum.	4.8	4.8	4.8	4.0	4.8	4.8	4.8	5.6	4.8	4.8	4.8	4.0	4.8	4.8	4.8	5.6	4.8	4.8	4.8	4.0	4.8	4.8	4.8	5.6
Refrig, Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cryogenic Storage	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Support Total	8.3	8.3	8.3	7.5	8.3	8.3	8.3	9.1	8.3	8.3	8.3	7.5	8.3	8.3	8.3	9.1	8.3	8.3	8.3	7.5	8.3	8.3	8.3	9.1
LOADS - Experiments																								
Life Sciences	6.0	8.0	6.0	6.0	6.0	6.0	6.0	6.0	8.0	8.0	8.0	6.0	8.0	8.0	8.0	6.0	6.0	8.0	6.0	6.0	6.0	8.0	6.0	6.0
Earth Resources	0.2	0.2	0.2	0.2	0.2	0.2	4.8	6.4	4.8	0.2	0.2	0.2	4.8	6.4	4.8	0.2	0.2	0.2	4.8	6.4	4.8	0.2	0.2	0.2
Atmospheric Sciences	0.1	0.1	1.5	2.3	1.5	0.1	0.1	0.1	0.1	1.5	2.3	1.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.5	2.3	1.5
Meteorological Radar	0.2	0.2	8.0	0.2	0.2	8.0	0.2	0.2	8.0	0.2	0.2	0.2	0.2	0.2	8.0	0.2	0.2	8.0	0.2	0.2	8.0	0.2	0.2	0.2
Experiment Total	6.5	8.5	15.7	8.7	7.9	14.3	11.1	12.7	20.9	9.9	10.7	7.9	13.1	14.7	20.9	6.5	6.5	16.3	11.1	12.7	18.9	9.9	8.7	7.9
Module Load Profile, kW	14.8	16.8	24.0	16.2	16.2	22.6	19.4	21.8	29.2	18.2	19.0	15.4	21.4	23.0	29.2	15.6	14.8	24.6	19.4	20.2	27.2	18.2	17.0	17.0
Total energy: 481.2 kW Hr																								
Average load: 20.05																								
Low: 14.8 kW																								
High: 29.2 kW																								

TABLE 3-5.

ACTIVITIES AND LOAD PROFILE MODULE: MPL

	TIME/HOURS																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	1
LOADS - Support																								
ECLSS, illum.	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	5.6	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Refrig, Freezer	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cryogenic Storage	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Support Total	7.5	7.5	7.5	7.5	7.5	7.5	7.5	8.3	8.3	8.3	8.3	7.5	8.3	8.3	8.3	9.1	8.3	8.3	8.3	7.5	8.3	8.3	8.3	8.3
LOADS - Material Processing																								
Biological Experiments	0	0	0	0	0	0	0	2	9	6	9	6	9	6	9	2	0	0	0	0	0	0	0	0
Metallurgical Experiments	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	12	12	2	22	22	12	2
Crystal Production	40	40	40	40	40	40	40	40	40	40	40	5	5	5	0	60	40	40	40	40	40	40	40	40
Processing Total	40	40	40	40	40	40	40	42	49	46	49	11	14	11	9	62	62	52	52	42	62	62	52	42
Module Load Profile, kW	47.5	47.5	47.5	47.5	47.5	47.5	47.5	50.3	57.3	54.3	57.3	18.5	22.3	19.3	17.3	71.1	70.3	60.3	60.3	49.5	70.3	70.3	60.3	50.3
Total Energy: 1191.8 kW Hr																								
Average Load: 49.6 kW																								
Low: 17.3 kW																								
High: 71.1 kW																								

TABLE 3-6.

ACTIVITIES AND LOAD PROFILE MODULE: CM

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
ECLSS, illum.	3.8	3.8	3.8	3.8	3.8	3.8	3.8	4.6	3.8	3.8	3.8	3.0	3.8	3.8	3.8	4.6	3.8	3.8	3.8	3.0	3.8	3.8	3.8	4.6
Beam Builder	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Assembly fixture motors	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
EVA assembly tools	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
EMU Servicing	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Module Load Profile	15.0	15.0	15.0	14.2	15.0	15.0	15.0	15.8	15.0	15.0	15.0	14.2	15.0	15.0	15.0	15.8	15.0	15.0	15.0	14.2	15.0	15.0	15.0	15.8

Total Energy: 360 kW Hr

Average Power: 15 kW

Low: 14.2 kW

High: 15.8 kW

TABLE 3-7.

ACTIVITIES AND LOAD PROFILE MODULE: CRANE

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1								■	■	■	■	▨	■	■	■	■								
OPERATIONAL SHIFT 2																■	■	■	■	▨	■	■	■	■
OPERATIONAL SHIFT 3	■	■	■	▨	■	■	■																	
NO. OF CREWMEN IN MODULE:	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
ECLSS, illum., motors	5.5	5.5	5.5	2.0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	2.0	5.5	5.5	5.5	5.5	5.5	5.5	5.5	2.0	5.5	5.5	5.5	5.5

Total Energy: 121.5 kW Hr

Average Power: 5.06 kW

Low: 2.0 kW

High: 5.5 kW

TABLE 3-8.

ACTIVITIES AND LOAD PROFILE MODULE: CCM

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	7	9	7	8	3	8	9	5	6	8	5	10	3	8	9	5	7	9	6	10	3	7	8	5
Activities - Control Center	3	2	2	1	1	2	2	3	3	2	2	1	1	2	2	3	3	2	2	1	1	2	2	3
- Eat	0	7	0	5	2	6	0	0	0	6	0	6	2	6	0	0	0	7	0	6	2	5	0	0
- Wardroom	4	0	5	2	0	0	7	2	3	0	3	3	0	0	7	2	4	0	4	3	0	0	6	2
LOADS																								
ECLSS, illum.	9.6	11.2	9.6	10.4	6.4	10.4	11.2	8.0	8.8	10.4	8.0	12.0	6.4	10.4	11.2	8.0	9.6	11.2	8.8	12.0	6.4	9.6	10.4	8.0
Food Storage & Preparation	0.5	0.7	0.5	0.7	0.6	0.7	0.5	0.5	0.5	0.7	0.5	0.7	0.6	0.7	0.5	0.5	0.5	0.7	0.5	0.7	0.6	0.7	0.5	0.5
C & D	0.4	0.5	0.4	0.2	0.4	0.5	0.4	0.4	0.4	0.5	0.4	0.2	0.4	0.5	0.4	0.4	0.4	0.5	0.4	0.2	0.4	0.5	0.4	0.4
Data Processing	4.0	5.0	4.0	2.0	4.0	5.0	4.0	4.0	4.0	10.0	8.0	2.0	8.0	10.0	8.0	8.0	8.0	10.0	8.0	2.0	8.0	10.0	8.0	8.0
Communications	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	0.6	0.4	0.6	0.8	0.6	0.6	0.6	0.8	0.6	0.4	0.6	0.8	0.6	0.6
Load Profile, kW	14.9	17.8	14.9	13.7	11.8	17.0	16.5	13.3	18.3	22.4	17.5	15.3	16.0	22.4	20.7	17.5	19.1	23.2	18.3	15.3	16.0	21.6	19.9	17.5
Total Energy: 420.9 kW Hr																								
Average Load: 17.54 kW																								
Low: 11.8 kW																								
High: 23.2 kW																								

TABLE 3-9.

ACTIVITIES AND LOAD PROFILE MODULE: CHM #1

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	5	4	4	6	7	3	3	3	4	3	4	4	6	3	3	3	4	3	4	5	7	4	4	4
ACTIVITIES - Sleep (S)	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4
- Pers. Hygiene (PH)	1	0	0	1	1	0	0	0	1	0	1	1	0	0	0	0	1	0	1	1	1	0	0	0
- Discretionary (H)	0	0	0	1	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	3	0	0	0
LOADS																								
Crew independent: 4 kW	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Crew dependent -																								
Sleeping: 0.5 kW ea.	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2
Awake: 0.8 kW ea.	0	0	0	0.8	1.6	0	0	0	0	0	0	0	2.4	0	0	0	0	0	0	0.8	2.4	0	0	0
PH Equipment: 0.5 kW ea. use	0.5	0	0	0.5	0.5	0	0	0	0.5	0	0.5	0.5	0	0	0	0	0.5	0	0.5	0.5	0.5	0	0	0
Load Profile, kW	6.5	6.0	6.0	7.3	8.1	5.5	5.5	5.5	6.0	5.5	6.0	6.0	7.9	5.5	5.5	5.5	6.0	5.5	6.0	6.8	8.4	6.0	6.0	6.0
Total Energy: 149 kW Hr																								
Average Load: 6.2 kW																								
Low: 5.5 kW																								
High: 8.4 kW																								

TABLE 3-10.

ACTIVITIES AND LOAD PROFILE MODULE: CHM #2

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1																								
OPERATIONAL SHIFT 2																								
OPERATIONAL SHIFT 3																								
NO. OF CREWMEN IN MODULE:	4	3	4	5	6	5	4	4	5	4	5	5	6	4	3	3	4	3	4	4	5	4	3	3
ACTIVITIES - Sleep (S)	3	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
- Pers. Hygiene (PH)	0	0	1	1	1	1	0	0	0	0	1	1	0	1	0	0	0	0	1	1	0	1	0	0
- Discretionary (H)	1	0	0	1	2	0	0	0	1	0	0	0	2	0	0	0	1	0	0	0	2	0	0	0
LOADS																								
Crew independent: 4 kW	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Crew dependent -																								
Sleeping: 0.5 kW ea.	1.5	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Awake: 0.8 kW ea.	0.8	0	0	0.8	1.6	0	0	0	0.8	0	0	0	1.6	0	0	0	0.8	0	0	0	1.6	0	0	0
PH Equipment: 0.5 kW ea. use	0	0	0.5	0.5	0.5	0.5	0	0	0	0	0.5	0.5	0	0.5	0	0	0	0	0.5	0.5	0	0.5	0	0
Load Profile, kW	6.3	5.5	6.0	6.8	7.6	6.5	6.0	6.0	6.8	6.0	6.5	6.5	7.6	6.0	5.5	5.5	6.3	5.5	6.0	6.0	7.1	6.0	5.5	5.5
Total Energy: 149 kW Hr																								
Average Load: 6.2 kW																								
Low: 5.5 kW																								
High: 7.6 kW																								

TABLE 3-11.

ACTIVITIES AND LOAD PROFILE MODULE: BM

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1								■	■	■	■	▨	■	■	■	■								
OPERATIONAL SHIFT 2																■	■	■	■	▨	■	■	■	■
OPERATIONAL SHIFT 3	■	■	■	▨	■	■	■																	■
NO. OF CREWMEN IN MODULE:	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
ACTIVITIES																								
Airlock Operations						10 kW for 0.16 Hr								10 kW for 0.16 Hr								10 kW for 0.16 Hr		
Airlock & Pumpdown Power, etc	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0.2
ECLSS, O_2 Regen.	10.	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10.	10
Suit drying & reconditioning	1	1.	1.	2.	2.	2.	2.	1.	1.	1.	1.	2.	2.	2.	2.	1.	1.	1.	1.	2.	2.	2.	2.	1.
Module Load Profile, kW	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2	11.2	11.2	11.2	12.2	12.3	12.3	12.2	11.2

Total Energy: 281.4 kW Hr

Average Power: 11.72 kW

Low: 11.2 kW

High: 12.3 kW

TABLE 3-12.

ACTIVITIES AND LOAD PROFILE MODULE: LM

	TIME/HOURS																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
OPERATIONAL SHIFT 1								▬	▬	▬	▬	▨	▬	▬	▬	▬								
OPERATIONAL SHIFT 2																▬	▬	▬	▬	▨	▬	▬	▬	▬
OPERATIONAL SHIFT 3	▬	▬	▬	▨	▬	▬	▬	▬																▬
NO. OF CREWMEN IN MODULE:																								
ECLSS, illum. & refrig, freezer	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total Energy: 48 kW Hr																								
Average Power: 2.0 kW																								
Low: 2.0 kW																								
High: 2.0 kW																								

TABLE 3-13.

ACTIVITIES AND LOAD PROFILE MODULE: PM*

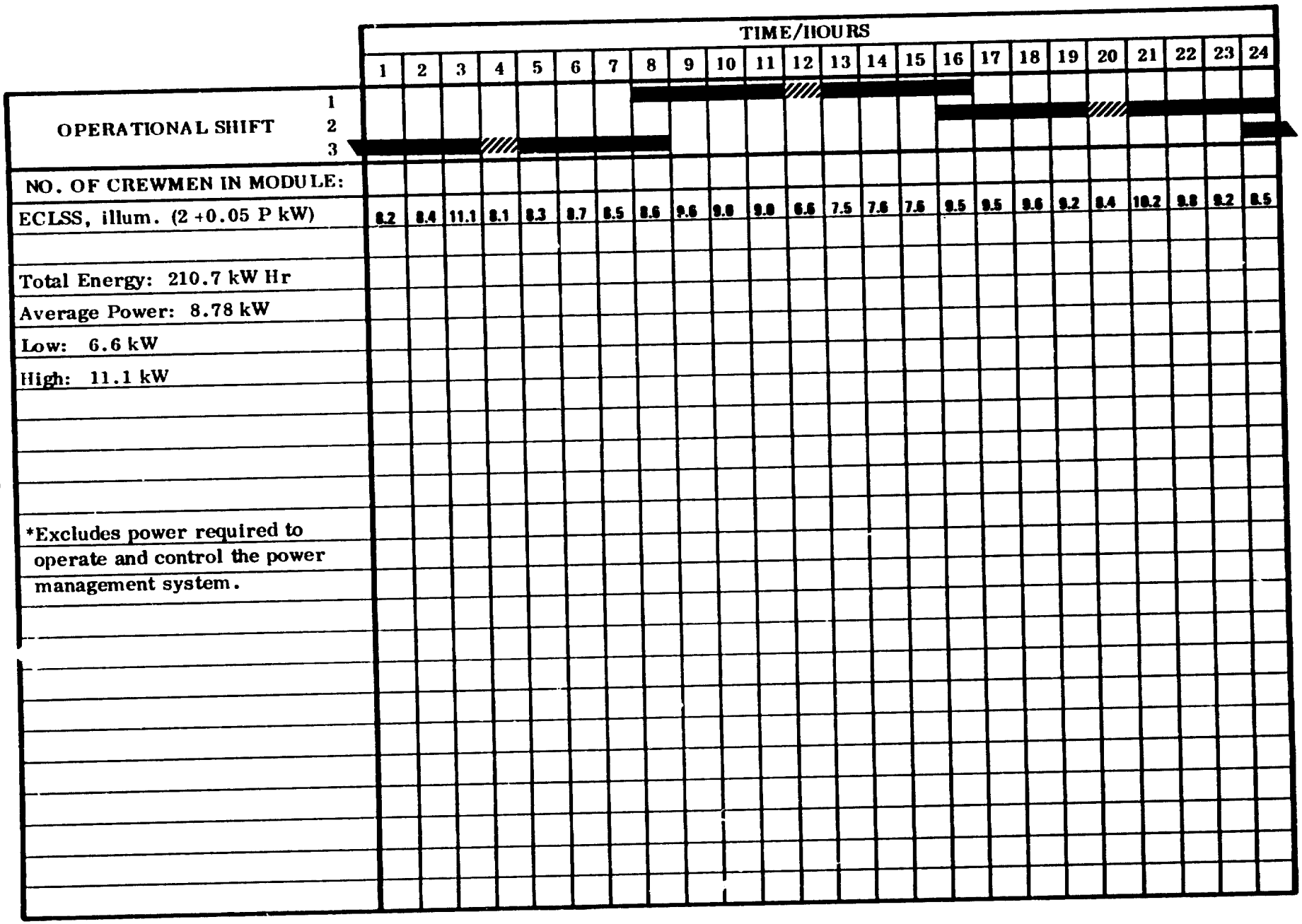

TABLE 3-14.

CREW ASSIGNMENTS & LOCATIONS

OPERATIONAL SHIFT			TIME/HOURS																					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		1																								
		2																								
		3																								
CREWMAN NO. & ASSIGNMENT	CHM NO.	SHIFT NO.																								
1 Control Center	1	1	S_1	S_1	S_1	S_1	S_1	E	W	1	1	1	1	E	1	1	1	1	W	E	PH_1	W	H_1	S_1	S_1	S_1
2 Control Ctr & Roving	1	1	S_1	S_1	S_1	S_1	S_1	E	W	W	1	1	1	1	E	1	1	1	1	E	W	PH_1	H_1	S_1	S_1	S_1
3 Control Center	2	2	W	E	PH_2	W	H_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	E	W	1	1	1	1	E	1	1	1	1
4 Control Ctr & Roving	1	2	1	E	W	PH_1	H_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	W	1	1	1	1	E	1	1	1
5 Control Center	1	3	1	1	1	E	1	1	1	1	W	E	PH_1	W	H_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	1
6 Control Ctr & Roving	1	3	1	1	1	1	E	1	1	1	1	E	W	PH_1	H_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	W
7 MDL	1	1	S_1	S_1	S_1	S_1	S_1	E	W	1	1	1	1	E	1	1	1	1	PH_1	E	W	W	H_1	S_1	S_1	S_1
8 MDL	1	2	PH_1	E	W	W	H_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	1	1	1	1	E	1	1	1	1
9 MDL	1	3	1	1	1	E	1	1	1	1	PH_1	E	W	W	H_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	1
10 MPL	1	1	S_1	S_1	S_1	S_1	S_1	E	W	1	1	1	1	E	1	1	1	1	W	E	W	H_1	PH_1	S_1	S_1	S_1
11 MPL	1	2	W	E	W	H_1	PH_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	S_1	E	W	1	1	1	1	E	1	1	1	1
12 CM	2	1	S_2	S_2	S_2	S_2	S_2	E	W	1	1	1	1	E	1	1	1	1	W	E	PH_2	W	H_2	S_2	S_2	S_2
13 CM	2	2	W	E	W	PH_2	H_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	E	W	1	1	1	1	E	1	1	1	1
14 CM	2	3	1	1	1	E	1	1	1	1	W	E	PH_2	W	H_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	E	W	1
15 Crane	2	1	S_2	S_2	S_2	S_2	S_2	E	W	1	1	1	1	E	1	1	1	1	W	E	W	PH_2	H_2	S_2	S_2	S_2
16 Crane	2	2	W	E	W	H_2	PH_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	E	W	1	1	1	1	E	1	1	1	1
17 Crane	2	3	1	1	1	E	1	1	1	1	W	E	W	PH_2	H_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	E	W	1
18 EVA	2	1	H_2	E	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	B	E	B	1	1	1	1	1	1	B	E	PH_2	W	W
19 EVA	2	2	1	1	1	B	E	PH_2	W	W	H_2	E	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	S_2	B	E	B	1	1
20 EVA	2	3	S_2	S_2	B	E	B	1	1	1	1	1	1	B	E	PH_2	W	W	H_2	E	S_2	S_2	S_2	S_2	S_2	S_2

TABLE 3-15.

CREW ACTIVITIES AND LOCATIONS MODULE: ALL

OPERATIONAL SHIFT		TIME/HOURS																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	1																								
	2																								
	3																								
LOCATION	TOTAL DAILY HOURS																								
MDL	24	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
MPL	16	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	1
CM	24	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
Crane	24	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2	1	1	1	0	1	1	1	2
CCM Total	165	7	9	7	8	3	8	9	5	6	8	5	10	3	8	9	5	7	9	6	12	3	7	8	5
(Eat)	(60)	(0	7	0	5	2	6	0	0	0	6	0	6	2	6	0	0	0	7	0	6	2	5	0	0)
(Wardroom)	(57)	(4	0	5	2	0	0	7	2	3	0	3	3	0	0	7	2	4	0	4	3	0	0	6	2)
(Control Center)	(48)	(3	2	2	1	1	2	2	3	3	2	2	1	1	2	2	3	3	2	2	1	1	2	2	3)
CHM #1	100	5	4	6	7	3	3	3	3	4	3	4	4	6	3	3	3	4	3	4	5	7	4	4	4
(S_1)	(80)	(4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4)
(PH_1)	(10)	(1	0	0	1	1	0	0	0	1	0	1	1	0	0	0	0	1	0	1	1	1	0	0	0)
(H_1)	(10)	(0	0	0	1	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	3	0	0	0)
BM	9	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0
EVA	18	1	1	1			1	1	1	1	1	1			1	1	1	1	1	1			1	1	1
CHM #2	100	4	3	4	5	6	5	4	4	5	4	5	5	6	4	3	3	4	3	4	4	5	4	3	3
(S_2)	(80)	(3	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3)
(PH_2)	(10)	(0	0	1	1	1	1	0	0	0	0	1	1	0	1	0	0	0	0	1	1	0	1	0	0)
(H_2)	(10)	(1	0	0	1	2	0	0	0	1	0	0	0	2	0	0	0	1	0	0	0	2	0	0	0)
LM (Infrequent)																									
PM (Infrequent)																									
Total		20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Airlock Operations																									

Several high power demands can be best met by supply of unregulated (e.g., 120 -250 volt) DC power to the loads, and incorporation of voltage/frequency conversion and regulation in the load equipment. For example, the high speed turbomachinery used in a refrigeration plant is best driven by high frequency AC motors. The high frequency inverters would thus be built into the propellant storage facility rather than the PMS.

Table 3-16 summarizes the load voltage types and power levels for each of the space platform modules, based upon the representative day requirements developed in Section 3.2.1, and the additional loads which would sometimes be encountered. The power levels shown for each of the voltage types are the envelope of requirements for each module and are not all connected simultaneously. However, the interfaces (disconnects and conductors) each must be sized to handle at least these levels.

Table 3-16. Voltage types and maximum power levels*.

LOAD LOCATION	HIGH VOLTAGE		LOW VOLTAGE	400 ± 1 Hz, 3φ
	REGULATED 115 ± 5 VDC	UNREGULATED TBD	REGULATED 28 ± 4 VDC	115/200 VAC
MULTI-DISCIPLINE LAB	20	(500)(1)	15	20
MATERIALS/PROCESSING LAB	20	60	10	20
CONSTRUCTION MODULE	20	(75)(2)	10	20
CRANE	5	—	2	5
CONTROL CENTER	20	—	10	20
CREW HABITAT #1	3	—	4	2
CREW HABITAT #2	3	—	4	2
BERTHING MODULE	15	50(3)	20(4)	5
LOGISTICS MODULE	—	—	2	—
POWER MANAGEMENT	5	—	10	5

NOTES:

(1) INTERMITTENT 500 kW FOR PLASMA PHYSICS EXPERIMENT
(2) INTERMITTENT 75 kW FOR MICROWAVE POWER TRANSMISSION ANTENNA TEST
(3) CONTINUOUS 50 kW FOR O_2/H_2 RELIQUEFACTION EQUIPMENT
(4) INCLUDES 14 kW FOR ORBITER SUPPORT

*Not all connected simultaneously

3.2.3 LOAD CRITICALITY. The PMS shall distribute electrical power to the loads over buses of three types: main, essential, and emergency. The loads will be connected to these buses in accordance with the criticality of their functions. Table 3-17 lists typical types of loads and their relative priorities. In the event of unanticipated power interruptions that cannot be solved by automatic switching within the PMS, the system will automatically begin load shedding in accordance with the priorities shown until the load demand is reduced to the electrical power system output capability. The relative priorities shown in the table may be reordered by reprogramming the control system.

Table 3-17. Load priorities.

BUSES	SPACE PLATFORM LOADS	PRIORITY
MAIN	O_2/H_2 RELIQUEFACTION PLANT	LOW ↑
	CONSTRUCTION EQUIPMENT	
	NORMAL EXTERIOR ILLUMINATION	
	EXPERIMENT EQUIPMENT	
	ORBITER SUPPORT	
ESSENTIAL	NORMAL EC/LSS	
	NORMAL INTERIOR ILLUMINATION	
	NORMAL COMMAND, CONTROL & DATA HANDLING	
	NORMAL ATTITUDE CONTROL	
	MAINTENANCE EQUIPMENT	
	FOOD STORAGE & PREPARATION	
	WASTE MANAGEMENT	
	LABORATORY REFRIGERATORS & FREEZERS	
	PERSONAL HYGIENE	
EMERGENCY	MINIMUM EC/LSS	
	MINIMUM ILLUMINATION, INTERIOR & EXTERIOR	
	MINIMUM COMMAND, CONTROL & DATA HANDLING	
	MINIMUM ATTITUDE CONTROL	
	CRANE CAPSULE — RETURN TO EGRESS HATCH	
	EVA SUIT RECHARGE & AIRLOCK OPERATION	
	REPAIR EQUIPMENT	
	RENDEZVOUS & DOCKING EQUIPMENT	
	RESCUE EQUIPMENT	↓ HIGH

Planned power interruptions, e.g., for maintenance work on the electrical power system, would generate a different load priority ranking because of different crew work assignments.

3.2.4 EMERGENCY POWER. The PMS shall control and distribute space platform emergency power at the voltages and power levels listed in Table 3-18. The power source(s) may be batteries or fuel cells. The emergency source(s) is not part of the PMS but is an element of the electrical power system that interfaces with the PMS.

The source shall provide energy for operating the space platform at emergency load levels for 96 hours with a full crew, or for 164 hours with a crew of reduced size (nominally 13).

(NOTE: If fuel cells are used as the emergency power source and if LO_2/LH_2 storage tanks are berthed for OTV propellant resupply, it could be possible to design the emergency power source to operate for an extended period of time)

The PMS shall also be designed to receive 28VDC electrical power from a docked Orbiter and distribute and control power to the emergency loads. This mode of operation would apply when the emergency power source has been exhausted and a reduced size crew is aboard the space platform to perform repair work.

Table 3-18. Emergency power requirements have been analyzed in detail.

LOCATION	POWER (kW) WITH FULL CREW COMPLEMENT			POWER (kW) WITH REDUCED CREW COMPLEMENT @28 VDC
	TOTAL AC + DC	DC 28V	AC 115V	
MULTI-DISCIPLINE LAB	0.5	0.5	0	0.5
MATERIAL/PROCESSING LAB	0.5	0.5	0	0.5
CONSTRUCTION MODULE	0	0	0	0
CRANE	0	0	0	0
CONTROL CENTER	2.5	1.5	1.0	1.5
CREW HABITAT #1	2.5	1.5	1.0	1.5
CREW HABITAT #2	2.5	1.5	1.0	0.5
BERTHING MODULE	2.5	1.5	1.0	1.5
LOGISTICS MODULE	0.5	0.5	0	0.5
POWER MANAGEMENT	0.5	0.5	0	0.5
TOTALS	12.0	8.0	4.0	7.0

3.3 SYSTEM CHARACTERISTICS

3.3.1 ELECTRICAL. The major power distribution interfaces are located at the module docking ports as illustrated in Figure 3-3. As a minimum, the voltages and power levels required for each module as shown in Table 3-16 are required at the respective module docking ports.

However, in the interest of standardizing hardware and maximizing operational flexibility, it is desired that standard power interfaces be used at each module docking port. This would enable modules to be located at any one of the docking ports of the berthing module. Thus the power levels and voltage types required at each of the module docking port interfaces shall be:

a. High Voltage DC -

   (1) Regulated 115 ± 5 volt: 25 kW
   (2) Unregulated 120 - 250 volt: 75 kW

b. Low Voltage DC - Regulated 28 ± 4 volt: 14 kW

c. AC Power 400 Hz, 3 phase - Regulated (±5%) 115/200 volt: 25 kW

(NOTE: These interface power and voltage levels pertain to the radical docking ports and the berthing module (BM) axial port used for construction equipment. The BM axial port that interfaces with the power module would not use the standard power interface because the power levels at this interface are much higher).

Electrical power distribution through the standard docking interface panels must be provided on the appropriate types of buses (i.e., main, essential, emergency) according to the criticality of the load types. The specific types, numbers, and sizes of conductors shall be determined by design trade studies.

The PMS shall also provide the means to supply up to 500 kW of unregulated high voltage DC power to the MDL on a temporary basis for the plasma physics experiments. This power shall not pass through the electrical panel of the standard module docking interface.

Two of the radial docking ports will be used to berth a shuttle Orbiter during resupply missions. Normally, only one Orbiter would be present but two might be docked simultaneously under emergency circumstances.

While the Orbiter is berthed to the platform cluster during normal resupply missions, its fuel cells will be off line and all Orbiter operating power will be supplied by the platform thru the berthing interface.

Electrical interfaces shall be made with the Orbiter main bus system as follows:

Main Bus A:	5 kW, 30 ± 2 VDC
Main Bus B:	5 kW, 30 ± 2 VDC
Main Bus C:	4 kW, 30 ± 2 VDC
TOTAL	14 kW

a. Isolation Requirements - Buses A and C may be paralleled. Bus B must be isolated from Buses A and/or C.

b. Physical Requirements - The Orbiter main bus interfaces are physically located in the Orbiter cargo bay at Station X_o = 693, starboard side.

The PMS shall also provide the capability of receiving emergency power from the Orbiter as established in Section 3.2.4. Emergency power at levels up to 7 kW will be received from Orbiter Main Bus A at 30 ± 2 VDC.

3.3.2 PHYSICAL. All PMS components and assemblies when packaged or otherwise configured for delivery to orbit shall be compatible with shuttle Orbiter payload bay size, weight, and C.G. constraints, and shall withstand the Orbiter flight loads and environments defined in JSC 07700, Vol XIV, Section 4.2.

The requirements of ICD 2-19001, "Shuttle Orbiter/Cargo Standard Interfaces", shall apply.

3.3.3 ELECTROMAGNETIC COMPATIBILITY (EMC). The power management system (PMS) and its components shall be designed to meet the design intent of MIL-STD-1541 and MIL-STD-462 and applicable portions of MIL-E-6051.

3.3.4 GROUNDING. The PMS shall not employ the structure of the space platform or associated equipment as a ground return for power distribution or signal lines.

3.4 RELIABILITY AND LIFE.

The PMS shall be designed such that the electrical power system will have a minimum overall reliability factor of 0.9 for a ten year useful lifetime. This means that there will be a 90% probability that any desired voltage and power level (within the system design requirements) will be available when needed, at any load location.

This reliability may be achieved by various combinations of: (1) use of high reliability components; (2) use of on-line or off-line redundancy; and (3) preventive and corrective repair and/or replacement of units. The choice of method(s) shall be determined by safety and cost-effectiveness analyses and trade-offs.

Power management system design shall observe the reliability criteria listed in Table 3-19.

Table 3-19. PMS reliability criteria.

- No single failure or credible combination of failures will prevent system from operating in acceptable degraded mode of operation.
- System will employ redundant controls, power conditioning equipment and load paths.
- Control and monitoring circuits will employ independent, redundant power sources.
- At module/component failures, system will commence load shedding according to a predetermined hierarchy determined by loads analysis and establishment of criticalities.
- PMS design will be organized into subsections that provide for redundant main buses, essential-load buses and emergency buses.

3.5 MAINTAINABILITY

All components of the PMS that are subject to degradation, failure or wearout during the 10-year operational lifetime shall be designed for orbital replacement.

Components that must be transported within the pressurized modules of the cluster or that must pass thru airlocks shall be limited in size such that they will pass through a 1-meter-diameter hatch.

The PMS shall incorporate built-in test capabilities for fault diagnosis that will identify failed or degraded power system elements. The testing system shall maintain records of the system "health", identify trends as well as out-of-limit conditions, and provide test data that will make possible the prediction of remaining life of system elements and the forecasting of the required schedule for repairs and replacements.

Power management system design shall observe the maintainability criteria listed in Table 3-20.

Table 3-20. PMS maintainability criteria.

- System will be designed for on-orbit maintenance by replacement of failed modules/components.
- System will employ redundant controls, power conditioning equipment and load paths.
- System will use computer-controlled power management techniques with capabilities such as:
  - ▲ Continuously monitor system health and performance.
  - ▲ Detect and isolate faults.
  - ▲ Shift loads around failed equipment.
  - ▲ Predict incipient failures and isolate equipment.
  - ▲ Shut down and isolate failed equipment to prevent damage to other equipment
- System will be designed to selectively shut down sections for replacement of failed modules/components.
- Modules/components will be designed for ease of removal and replacement with appropriate mechanical latches, electrical connectors, fluid connectors, etc.

Specific requirements for inflight maintenance design and equipment access are specified in MSFC-STD-512A, Paragraphs 3.6.2.1 and 3.6.2.2, respectively.

When extravehicular activity (EVA) is employed for planned, unplanned, or contingency maintenance or repair, the requirements specified in NASA JSC-10615, "Shuttle EVA Description and Design Criteria", shall apply.

3.6 ENVIRONMENTAL CONDITIONS

The power management system (PMS) and its components shall be designed to designed to operate in low Earth orbit at altitudes from 370 to 650 km and inclinations from 28.5 to 90 deg. System design should also take into consideration potential operation at geostationary orbit. The system shall be designed to operate in the environmental conditions (i.e., pressure, radiation, meteoroid, and geomagnetic) defined in Section II of NASA TMX 53865, "Natural Environment Criteria for 1975 - 1985 NASA Space Stations", latest revision.

Emphasis shall be placed on designing the system to be free from electrical breakdown and arcing caused by outgassing, plasma effects, and spacecraft charging. NASA SP 208, "The Prevention of Electrical Breakdown in Spacecraft", shall be employed as a design guide.

PMS elements that normally operate in a pressurized environment shall continue to perform their intended function without overheating, malfunction, or electrical breakdown in the event that the surrounding pressure is reduced to near vacuum.

All PMS components and assemblies when packaged or otherwise configured for delivery to orbit shall withstand the Orbiter flight loads and environments defined in JSC 07700, Vol. XIV, Section 4.2.

3.7 SAFETY

The power management system (PMS) and its components shall be designed to assure the safety of the space platform and its crew. The system shall be designed in accordance with NASA JSC-11123, "STS Payload Safety Guidelines Handbook", Section 3.4, "Electrical Subsystems", and NASA MSFC-STD-512A, "Man/System Requirements for Weightless Environments", Section 3.5, "Safety".

Table 3-21 lists specific safety design criteria that have been established for the PMS.

3.8 HUMAN ENGINEERING

The power management system (PMS) and its components shall be designed in accordance with the man/machine requirements, guidelines, constraints, and criteria set forth in MSFC-STD-512A, supplemented by MIL-STD-1472B.

Emphasis shall be placed on assuring that PMS components and their installations meet the maintainability criteria established in Subsection 3.5 with regard to human reach and strength criteria, assessibility, and safety. Equipment items shall be equipped with handling or grasping means suitable for EVA crewmen and/or Shuttle RMS end effectors.

Maintenance operations shall not require more than two crewmen to accomplish any physical removal/replacement or repair task.

Table 3-21. PMS safety criteria.

- Safety is a non-tradeable consideration in PMS design. No single failure or credible combination of failures shall result in injury to crew or damage to other equipment.
- The system shall incorporate redundant control and monitoring circuits. These shall employ independent, redundant power sources.
- System design shall provide positive power removal capability before disconnecting and reconnecting modules/components.
- Plugs, receptables and fluid lines shall be keyed or physically restrained, etc., so that it is physically impossible to mismate them.
- Circuitry having capacitor output stages shall be provided with bleeddown circuits.
- Coolant loops in inhabited areas shall not employ toxic fluids.
- Equipment cases shall be at ground potential to prevent possibility of shock hazard to personnel or shorting to ground by conductive debris or liquid leakage.
- Equipment surfaces in inhabited areas shall not exceed 45C (113F) where personnel contact may occur. Shields shall be provided for surfaces exceeding this temperature.
- Materials employed for insulation, circuitboards, barrier strips, coatings, etc., shall not outgas toxic vapors or present flammability hazards under both normal and abnormal operating conditions.